Odor-Baited Trap Trees: A Novel Management Tool for Plum Curculio (Coleoptera: Curculionidae)

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ABSTRACT The plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), one of the most important pests of apple (*Malus* spp.) in eastern and central North America, historically has been managed in New England apple orchards by three full block insecticide applications. Efforts to reduce insecticide inputs against plum curculio include perimeter row sprays, particularly after petal fall, to control immigrating adults. The odor-baited trap tree approach represents a new reduced input strategy for managing plum curculio based on the application of insecticides to a few perimeter-row trap trees rather than the entire perimeter row or full orchard block. Here, we compared the efficacy of a trap tree approach with perimeter row treatments to manage populations after petal fall in commercial apple orchards in 2005 and 2006. Injury was significantly greater in trap trees compared with unbaited perimeter row treated trees in both years of the study. In 2005, heavy rains prevented growers from applying insecticide applications at regular intervals resulting in high injury in nearly all blocks regardless of type of management strategy. In 2006, both the trap-tree and perimeter-row treatments prevented penetration by immigrating populations and resulted in economically acceptable levels of injury. The trap tree management strategy resulted in a reduction of ≈70% total trees being treated with insecticide compared with perimeter row sprays and 93% compared with standard full block sprays.

KEY WORDS plum curculio, *Conotrachelus nenuphar*, weevil, pheromone, integrated pest management

Plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), is one of the most important insect pests of pome and stone fruit in eastern and central North America (Racette et al. 1992, Vincent et al. 1999, Leskey and Wright 2004b). In the northeastern United States, plum curculio has been managed by applying three full block applications of an organophosphate insecticide (Koehler 2003) in the absence of monitoring tactics. After petal fall, however, the question as to need for and timing of subsequent insecticide applications made against plum curculio has been difficult for growers to pinpoint because of lack of a reliable monitoring technique. Recently, Prokopy et al. (2003, 2004) developed a trap tree monitoring strategy for plum curculio oviposition activity. This approach calls for baiting one apple (*Malus* spp.) tree in the perimeter row with a synergistic two-component lure (Piñero and Prokopy 2003) composed of the synthetic host plant-derived volatile benzaldehyde and the synthetic male-produced aggregation pheromone grandisoic acid (Eller and Bartelt 1996). This trap tree is subsequently monitored for signs of fresh oviposition injury, thereby allowing growers to determine need for and timing of subsequent insecticide applications (Prokopy et al. 2003, 2004). The effectiveness of this approach to monitoring oviposition activity has been demonstrated recently in seven northeastern states (Piñero et al. 2006).

Along with the trap tree monitoring technique, two other approaches have been developed that can result in reductions in the overall amount of insecticide applied against plum curculio. They include a degree-day (DD) model and a perimeter row treatment strategy. Both rely on a full block insecticide application at petal fall to control the majority of the overwintered immigrating population. The degree-day model is based on oviposition injury and calls for maintaining insecticide residue on trees until the accumulation of 171 DD (base 10°C) after petal fall has been reached (Reissig et al. 1998). The second approach recommends all post petal fall insecticide treatments be applied to perimeter rows only rather than the entire

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orchard block (Chouinard et al. 1992, Vincent et al. 1997). Confining insecticide applications to perimeter rows results in significant reduction in insecticide inputs compared with the conventional three full block sprays.

More recently, a novel approach recommends applying insecticides to baited trap trees (originally used for monitoring) only rather than the entire perimeter row or full orchard block after petal fall. Preliminary studies (R.J.P., unpublished data) suggest that plum curculios can be managed effectively using this approach. By confining insecticide application to a few perimeter row trap trees after the full block petal fall insecticide application, even more substantial reductions in amount of insecticide applied can be made without compromising plum curculio control.

The objective of this project was to compare the efficacy of the trap tree and perimeter row management strategies to determine the extent to which satisfactory levels of plum curculio control could be achieved given the substantial reductions in insecticide use that these two approaches offer. Two specific questions were addressed: 1) does the presence of synthetic baits in apple trees result in significant aggregation of fruit injury in these specific tree canopies compared with unbaited tree canopies; and 2) can plum curculio injury be maintained at economically acceptable levels by using the trap tree management strategy? Studies were conducted in 2005 and 2006 in commercial apple orchards in New Hampshire and Vermont.

Materials and Methods

Orchard Setup. Five blocks were established within four commercial apple orchards in 2005; Poverty Lane Orchards in Lebanon, NH (two blocks), Apple Hill Orchard in Concord, NH (one block), Gould Hill Orchard in Contoocook, NH (one block), and Scott Farm in Brattleboro, VT (one block). Each block was divided into four ≈1-ha plots. Three of these plots were used to compare the novel trap tree management strategy with a perimeter row strategy. Within each of the three trap tree plots, four perimeter row trees (two in either perimeter row on each woods-facing side of the plot) were baited with four dispensers of benzaldehyde and a single dispenser of grandisoic acid. One of the three trap tree plots had perimeter-row, odor-baited trap trees only. The second trap tree plot included two standard masonite pyramid traps (Leskey and Wright 2004b) deployed near the trunk of each trap tree and baited with live adult plum curculios (maintained on a diet of cut apples) in the boll weevil collection device affixed to the top of the pyramid base. The remaining trap tree plot included unbaited pyramid traps deployed near the trunk of each trap tree (Fig. 1A). Pyramid traps were deployed to determine whether the presence of live conspecific adults within the vicinity of baited trap trees result in increased aggregation of fruit injury. The fourth plot in each block had no trap trees and was managed using perimeter row sprays after full petal fall insecticide application (Fig. 1A).

In 2006, eight blocks were established in the same commercial apple orchards used in 2005 studies: Poverty Lane Orchards (three blocks), Apple Hill Orchard (one block), Gould Hill Orchard (two blocks), and Scott Farm (two blocks). Each block was divided into two paired ≈2.5-ha plots to compare trap tree and perimeter row treatment management strategies only (Fig. 1B). In the trap tree plot, six perimeter row trees (three in either perimeter row on each side of the plot) were baited with four dispensers of benzaldehyde and a single dispenser of grandisoic acid.

Within all trap tree plots in 2005 and in 2006, the first trap tree was deployed ≈25 m from the end of the row, and trap trees were separated by ≈50 m within the row. Benzaldehyde dispensers consisted of 8 ml of a 9:1 neat solution of benzaldehyde:1,2,4-trichlorobenzene formulated into 15-ml capped polyethylene vials (PGC Scientific Corp., Gaithersburg, MD). Each vial was suspended inside an inverted colored plastic drinking cup (volume 266 ml) (Solo Cup Co., Urbana, IL) to minimize the potential negative impact of UV light on the stability of benzaldehyde. Based on release rate equations generated by Leskey and Zhang (2007), total release at 25°C would equal ≈228 mg/d per trap tree. Pheromone dispensers contained 35 mg of grandisoic acid (ChemTica, San Jose, Costa Rica); recent studies by Leskey and Zhang (2007) predicted that the release rate was ≈0.14 mg/d per trap tree at 25°C. The four benzaldehyde dispensers were deployed equidistantly throughout the outer third of the canopy and left for the entire season while the pheromone dispenser was deployed near the center of the tree (Prokopy et al. 2003, 2004) and replaced after ≈5 wk.

Deployment and Evaluation. All trap tree and perimeter row treatment plots were established during late bloom between 23–27 May in 2005 and 10–12 May in 2006. At petal fall, each grower applied a full block insecticide application (Table 1) Cumulative degree-days after petal fall (base 10°C) by using the oviposition model for timing insecticide sprays (Reissig et al. 1998) were calculated for each orchard. Temperature data entered into the degree-day model for Apple Hill and Gould Hill orchards, for Poverty Lane orchards, and for Scott Farms were based on weather data collected in Concord, NH, Lebanon, NH, and Keene, NH, respectively After petal fall, plum curculios were managed in the trap tree plots by using the trap tree management protocol or with perimeter row sprays. In trap tree plots, only the trap trees and the ends of rows on the outer edge of the most exterior plot (for experimental purposes to isolate the trap tree plot from plum curculios that could invade unprotected row ends) were subsequently treated with insecticide after the full block insecticide application at petal fall in 2005 (Fig. 1A) and in 2006 (Fig. 1B). The perimeter row treatment plot received insecticide sprays on three sides of the plot in 2005 (Fig. 1A) and on all four sides in 2006 (Fig. 1B) to control plum curculios after the full block petal fall treatment. Need for and timing

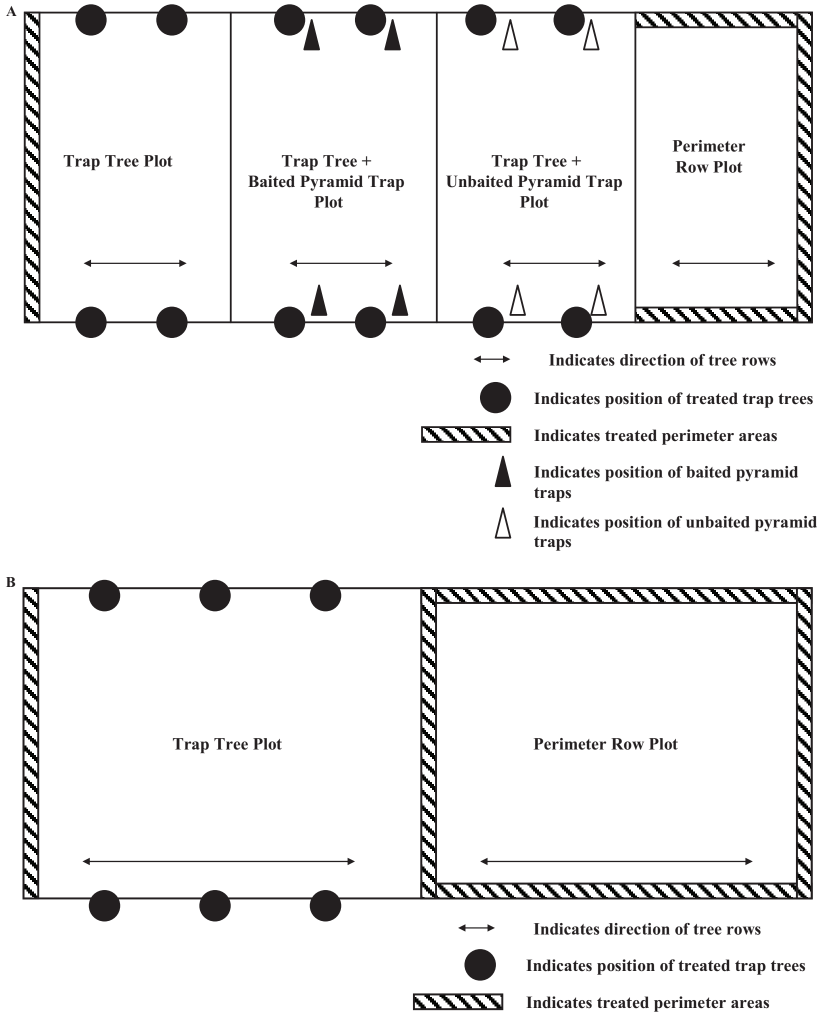

Fig. 1. (A) 2005 Layout of standard trap tree and perimeter row treated plots in commercial apple orchard blocks. (B) 2006 layout of paired trap tree and perimeter row treated plots in commercial apple orchard blocks.

of insecticide applications as well as material and rate used were decided by individual growers (Table 1).

In 2005, all experimental blocks received a full block petal fall spray directed at plum curculio followed by trap tree or perimeter row treatments (first cover) ≈1–2 wk later. Three of the five blocks received another trap tree or perimeter row treatment (second cover) ≈1 wk later (Table 1). Fruit injury evaluations were made from 19 July to 2 August. The total number of fruit with oviposition scars was recorded based on a sample of 25 fruit per tree in trap trees and in one peripherally located perimeter row tree immediately to the right and left of each trap tree in each trap tree plot as well as in unbaited control trees in the perimeter row treated plot. In addition, 100–125 fruit (up to 10 trees per row) were sampled from four to six interior rows; sampled trees were located behind and in a parallel line with the trap tree in trap tree plots or unbaited control tree in the perimeter row treated plots to provide a measure of efficacy of each treatment regime to protect fruit from plum curculio immigration and injury. Approximately 12,000 fruit from the combined trap tree plots and 3,600 fruit from the perimeter row treated plot were sampled.

In 2006, all experimental blocks received a full block petal fall spray directed at plum curculio followed by a trap tree or perimeter row treatments (first cover) ≈1–2 wk later (Table 2). Six of the eight blocks received another trap tree or perimeter row treatment (second cover) 7–10 d later, and the remaining two blocks received a final trap tree or perimeter row treatment (third cover) targeting plum curculio 7 d later (Table 2). Fruit injury evaluations were made from 10 to 12 July. The total number of fruit with oviposition scars was recorded based on a sample of 20 fruit per tree in trap trees in the trap tree plot and control trap trees in the perimeter row treated plot, and in peripherally located trees surrounding each trap tree and control trap tree for a total of up to 6,000 fruit per plot (Fig. 2). In addition, 20 interior trees (20

Table 1. Date (cumulative DD, after petal fall; base 10°C), material, and application rate of insecticides applied as a full block spray at petal fall and subsequent treatment applications to trap trees and perimeter rows at first, second, and third cover for plum curculio in 2005

Orchard	Petal fall	First cover	Second cover	Third cover
Apple Hill	2 June Carbaryl 4L[a] 60 oz/acre Calypso[c] 2 qt/acre	11 June (120 DD)[b] Imidan[1] 1 lb/100 8 June (77 DD)[b] Carbaryl 4L[c] 48 oz/acre	15–18 June (192 DD)[b] Imidan 1 lb/100	
Gould Hill	31 May–2 June Calypso 1.6 oz/100 Sevin XLR 5.5oz/100	9 June (98 DD)[b] Imidan 1 lb/acre	18 June (200 DD)[b] Imidan 1 lb/acre	
Poverty Lane (1/4 Mile)	9 June Sevin XLR 1 pt/100, Imidan 1 lb/100	19 June (101 DD)[d] Imidan 1 lb/100		
Poverty Lane (Main Farm)	5–11 June Sevin XLR 1 pt/100, Imidan 1 lb/100	19 June (143 DD)[d] Imidan 1 lb/100		
Scott Farm	1 June Avaunt 5 oz/acre	10 June (97 DD)[e] Avaunt 5 oz/acre	16 June (154 DD)[e] Avaunt 5 oz/acre	

[a] Applied to trap tree plots only.
[b] Cumulative degree days calculated using temp data obtained from Concord, NH.
[c] Applied to perimeter row treated plot only.
[d] Cumulative degree days calculated using temp data obtained from Lebanon, NH.
[e] Cumulative degree days calculated using temp data obtained from Keene, NH.

fruit per tree) were sampled along diagonal paths from opposing corners of each plot to provide a measure of efficacy of each treatment regime to protect fruit from plum curculio immigration and injury. In total, 400 fruit per trap tree and perimeter row treated plots were sampled.

Statistics. Data were analyzed separately for 2005 and 2006 by using the GLM procedure (SAS Institute 2003) to construct analysis of variance tables. Because there were no significant differences in the percentage of fruit injury found among the three trap tree plot treatments (standard trap tree, trap tree + baited pyramid traps, and trap tree + unbaited pyramid traps) in 2005, data were combined into a single trap tree treatment. In nearly all cases, each model included the after class variables: orchard and treatment. Proportion fruit injury data were subject to an ARCSIN SQRT transformation. Models were constructed to compare percentage of fruit injury in 1) trap trees and perimeter row treated unbaited control trees in 2005 (this model did not include orchard as a class variable because unbaited control trees were sampled on a per plot basis) and 2006; 2) trap trees and lateral perimeter trees located to the immediate left and right of trap trees in 2005, and trap trees and lateral perimeter trees located in the border row of trap tree plots in 2006 (Fig. 2); 3) trap trees and nearest neighbor trees followed by trap tree zones and peripheral tree zones within trap tree plots in 2006 (Fig. 2); and 4) interior trees within trap tree and perimeter row treated plots in 2005 and in 2006 as a measure of the effectiveness of the management strategies to protect fruit from plum curculio injury (these models did not include orchard as a class variable because trees were sampled on a per plot basis). When the GLM indicated significant differences in treatment or among orchard, multiple comparisons were calculated using Tukey's honestly significant difference (HSD) at $\alpha = 0.05$.

Table 2. Date (cumulative DD, after petal fall; base 10°C), material, and application rate of insecticides applied as a full block spray at petal fall and subsequent treatment applications to trap trees and perimeter rows at first, second, and third cover for plum curculio in 2006

Orchard	Petal fall	First cover	Second cover	Third cover
Apple Hill	27 May Carbaryl 4L 64 oz/acre	6 June (96 DD)[a] Avaunt 5 oz/acre	16 June (161 DD)[a] Avaunt 6 oz/acre	
Gould Hill	26 May Calypso 1.6 oz/100, Sevin XLR 5.5oz/100	5 June (97 DD)[a] Sevin XLR[b] 5.5oz/100	12 June (115 DD)[a] Imidan 0.96 oz/100	
Poverty Lane (1/4 Mile)	29 May Assail 2 oz/acre	6 June (70 DD)[c] Imidan[2] 1 lb/acre	13 June (104 DD)[c] Imidan 1 lb/acre	20 June (176 DD)[c] Imidan 1 lb/acre
Poverty Lane (Farnum Hill)	6 June Imidan 1 lb/acre	14 June (49 DD)[c] Imidan 1 lb/acre	22 June (129 DD)[c] Imidan 1 lb/acre	
Poverty Lane (Main Farm)	30 May Assail 2 oz/acre	6 June (59 DD)[c] Imidan[d] 1 lb/acre	13 June (93 DD)[c] Imidan 1 lb/acre	20 June (165 DD)[c] Imidan 1 lb/acre
Scott Farm	23 May Avaunt 5 oz/acre	6 June (103 DD)[e] Avaunt 5 oz/acre		

[a] Cumulative degree-days calculated using temp data obtained from Concord, NH.
[b] Applied to all rows as an additional thinning spray.
[c] Cumulative degree-days calculated using temp data obtained from Lebanon, NH.
[d] Indicates alternate row middle spray pattern.
[e] Cumulative degree-days calculated using temp data obtained from Keene, NH.

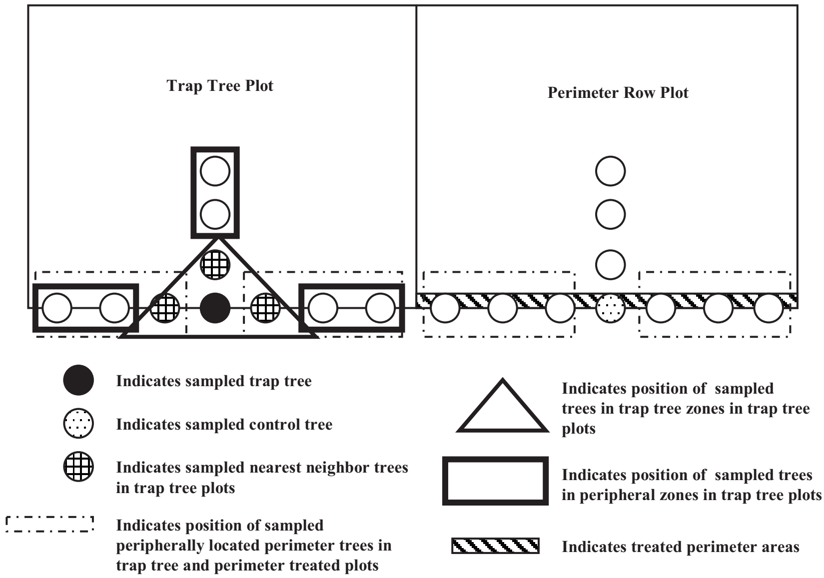

Fig. 2. Sampling regimes used in each trap tree and perimeter row treated plots in 2006.

Comparisons among orchards for samples taken from perimeter row treated trees in 2005, and from interior trees in 2005 and 2006 could not be calculated because samples were taken on a per plot basis.

Results

Trap Trees and Unbaited Control Trees. The model for fruit injury was significant both in 2005 ($F = 3.77$; df = 1, 68; $P = 0.05$) and in 2006 ($F = 4.40$; df = 8, 85; $P < 0.01$). The effect of treatment ($P < 0.001$) and orchard was significant in 2006 ($P = 0.04$). Significantly more injury was found within trap trees (22.90 ± 2.93%, mean ± SE) in trap tree plots compared with unbaited control trees (8.63 ± 3.34%) in perimeter row-treated plots in 2005 and in 2006 (6.80 ± 1.14 and 1.17 ± 0.50%, in trap tree and unbaited control trees, respectively). Within individual orchards, injury in trap trees and unbaited control trees ranged from 5.33 to 59.67% and from 1.67 to 18.67%, respectively, in 2005 and from 1.67 to 20.0% and from 0.0 to 4.17%, respectively, in 2006 (Table 3).

Trap Trees and Lateral Perimeter Trees. In 2005, the model for fruit injury was significant ($F = 48.57$; df = 5, 114; $P < 0.01$), with the effect of orchard ($P < 0.01$) and treatment ($P < 0.01$) being significant. Significantly more injury was present in trap trees (22.90 ± 2.93%) compared with laterally located pe-

Table 3. Mean percentage of injury (± SE) in baited trap trees and unbaited lateral trees in trap tree plots and mean percentage of injury in unbaited control trees in perimeter row treated plots in 2005 and 2006

Orchard	Trap tree plot		Perimeter row plot
	Trap trees[a]	Lateral trees[a]	Unbaited control trees
2005			
Apple Hill	59.67 ± 5.42a	46.67 ± 6.35a	18.67[b]
Gould Hill	11.33 ± 3.87bc	4.17 ± 1.31b	1.67[b]
Poverty Lane (Farnum Hill)	20.67 ± 3.15b	10.00 ± 1.77b	16.67[b]
Poverty Lane (Main Farm)	5.33 ± 1.65c	3.50 ± 1.28b	3.67[b]
Scott Farm	17.50 ± 2.70bc	5.67 ± 1.55b	2.50[b]
2006			
Apple Hill	8.00 ± 5.14ab	4.20 ± 1.71ab	0.00 ± 0.00a
Gould Hill (North)	20.00 ± 6.83a	3.19 ± 1.08ab	0.83 ± 0.05a
Gould Hill (South)	1.67 ± 1.05ab	2.50 ± 51.20ab	0.00 ± 0.00a
Poverty Lane (1/4 Mile)	3.33 ± 1.67ab	1.72 ± 0.72ab	0.00 ± 0.00a
Poverty Lane (Farnum Hill)	4.17 ± 2.38ab	2.75 ± 0.77ab	4.17 ± 2.20a
Poverty Lane (Main Farm)	9.17 ± 2.71ab	7.92 ± 3.30a	2.50 ± 1.15a
Scott Farm (North)	1.67 ± 1.67b	0.97 ± 0.60b	0.83 ± 0.06a
Scott Farm (South)	6.67 ± 3.07ab	1.80 ± 50.87ab	0.83 ± 0.06a

[a] Values followed by the same letter within the same column are not significantly different according to Tukey's HSD ($P < 0.05$).
[b] Could not calculate standard error values because samples taken on a per plot basis.

Table 4. Mean % injury (± SE) in trap tree and peripheral zones within trap tree plots in 2006

Orchard	Trap tree zone	Peripheral tree zone
Apple Hill	7.08 ± 4.10ab	2.69 ± 1.07a
Gould Hill (North)	6.88 ± 1.40ab	1.94 ± 0.76a
Gould Hill (South)	2.29 ± 0.75ab	1.52 ± 0.89a
Poverty Lane (1/4 Mile)	1.94 ± 0.55ab	2.25 ± 0.70a
Poverty Lane (Farnum Hill)	3.06 ± 1.31ab	1.83 ± 0.48a
Poverty Lane (Main Farm)	13.33 ± 4.01a	4.44 ± 2.41a
Scott Farm (North)	1.46 ± 1.04b	0.40 ± 0.42a
Scott Farm (South)	3.75 ± 1.51ab	1.50 ± 0.67a

Values followed by the same letter within the same column are not significantly different according to Tukey's HSD ($P < 0.05$).

rimeter trees (14.00 ± 2.54%) in trap tree plots. Within individual orchards, the amount of injury in laterally located perimeter trees ranged from 3.50 to 46.67% compared with from 5.33 to 59.67% in trap trees (Table 3).

The model for fruit injury also was significant in 2006 ($F = 4.40$; df = 8, 86; $P < 0.01$), with the effect of orchard ($P < 0.01$) being significant. Although the effect of treatment was not significant ($P = 0.21$), greater amounts of injury were present in trap trees (6.80 ± 1.41%) compared with laterally located perimeter trees (3.21 ± 0.58%) within trap tree plots. Within orchards, the amount of injury in laterally located perimeter trees ranged from 0.97 to 7.92% compared with from 1.67 to 20.0% in trap trees (Table 3).

Trap Tree and Peripheral Zones. In 2006, there was no significant difference between injury in trap trees and nearest neighbor trees in trap tree plots ($F = 0.57$; df = 1, 86; $P = 0.45$). We then compared injury in trap tree and peripheral zones; the model for fruit injury was significant ($F = 5.45$; df = 8, 86; $P < 0.01$). The effect of orchard ($P < 0.01$) and treatment ($P < 0.01$) were both significant. Significantly more injury (3.70 ± 0.64%) was present within the trap tree zones than in peripherally located tree zones (2.02 ± 0.44%). The percentage of fruit injury within trap tree zones ranged from 1.46 to 13.33, with significantly more injury detected in the Poverty Lane Main plot compared with the Scott Farm North plot, and from 0.40 to 4.44% in peripheral tree zones in particular orchards (Table 4).

Interior Fruit Protection. The model for fruit injury ($F = 2.32$; df = 5, 4; $P = 0.22$) was not significant in 2005. The percentage of fruit injury (5.23 ± 3.43%) in plots managed using the trap tree regime was not significantly different from percentage of injury (4.91 ± 1.61%) in plots managed with perimeter row sprays, respectively. Across orchards, injury in trap tree plots and perimeter row treated plots ranged from 0.67 to 18.92% and from 1.00 to 8.75%, respectively (Table 5).

In 2006, the model for fruit injury ($F = 2.08$; df = 8, 7; $P = 0.18$) was not significant. The percentage of fruit injury (0.88 ± 0.35%) in plots managed using the trap tree regime was not significantly different from percentage of injury (0.50 ± 0.22%) in plots managed with perimeter row sprays, respectively. Within orchards, injury in trap tree plots and perimeter row treated plots ranged from 0.00 to 2.50% and from 0.00 to 1.75%, respectively (Table 5).

Table 5. Mean percentage of fruit injury in interior trees within plots managed with trap tree and perimeter row treatment plots in 2005 and 2006

Orchard block	Trap tree plot	Perimeter row plot
2005		
Apple Hill	18.92	7.80
Gould Hill	0.67	1.00
Poverty Lane (Farnum Hill)	2.42	8.75
Poverty Lane (Main)	1.75	5.75
Scott Farm	2.43	1.25
2006		
Apple Hill	0.50	1.00
Gould Hill (North)	0.25	0.00
Gould Hill (South)	0.00	0.00
Poverty Lane (1/4 Mile)	0.50	0.50
Poverty Lane (Farnum Hill)	2.25	1.75
Poverty Lane (Main Farm)	2.50	0.25
Scott Farm (North)	0.00	0.50
Scott Farm (South)	1.00	0.00

Discussion

This study confirms that the presence of the synergistic blend of grandisoic acid and benzaldehyde (Piñero and Prokopy 2003) deployed within the canopies of perimeter-row apple trees between bloom and petal fall results in significant aggregation of fruit injury in those specific canopies compared with other unbaited trees as reported previously by Prokopy et al. (2003, 2004). These specific insecticide-treated trap tree canopies function as an "attract-and-kill" trap crop for adult plum curculios colonizing orchard trees after petal fall. This novel plum curculio management strategy combines elements of an attract-and-kill approach such that adults are attracted and aggregated in a particular area where they can be effectively controlled (Shelton and Badenes-Perez 2006). In apple orchards of eastern North America, this can be achieved by using the synergistic long-distance olfactory stimulus deployed in combination with a killing agent (Foster and Harris 1997), in this case insecticide-treated foliage and fruit.

The approach evaluated in the current study aims at managing plum curculio successfully with a concomitant reduction in insecticide use. Indeed, acceptable levels of plum curculio control were achieved particularly in 2006. In 2005, participant growers were prevented from entering their orchard blocks to apply insecticide (Table 1) at petal fall and shortly thereafter due to extremely heavy rains measuring over 100 cm during the active plum curculio season. As a result, there was increased vulnerability of apples to plum curculio injury in all plots, regardless of treatment strategy. In 2005, mean percentage of fruit injury in most plots managed using the trap tree strategy and perimeter row treatments reached well over 1.00% (Table 5), an unacceptable economical injury level in New England. In New Hampshire apple orchards in 2005, the mean percentage of fruit injury from plum curculio ranged from 0.0 to 3.4%, with an average of 0.62% recorded based on 25 surveyed orchards (A. Eaton, personal communication).

In 2006, growers participating in trap tree trials sprayed at appropriate intervals; consequently, the amount of injury in nearly all orchard plots managed using the trap tree strategy or perimeter row treatments was at or below 1.00% (Table 5), with the mean percentage injury across all orchards at 0.50% for trap tree and 0.88% for perimeter-treated plots. This result indicates that even though only a few odor-baited trap trees were sprayed in the trap tree plots, the trap tree strategy was as effective as perimeter row treatments for managing immigrating adults after petal fall. In New Hampshire apple orchards in 2006, the mean percentage of fruit injury from plum curculio ranged from 0.0 to 6.6%, with an average of 0.74% recorded based on 23 surveyed orchards (A. Eaton, personal communication).

A full block insecticide application at petal fall is required (R.J.P., unpublished data) in part because, on average, 60% of all immigrant adults have arrived at and penetrated to the interior rows of orchards by the time of petal fall (Piñero and Prokopy 2006). Our results demonstrate that insecticide applications confined to perimeter row trees in New England apple orchards can be substantially reduced compared with the conventional full block sprays, as demonstrated previously in Quebec orchards (Chouinard et al. 1992, Vincent et al. 1997). Remarkably, treating only the trap trees and the ends of rows in trap tree plots resulted in a reduction of ≈70% of total trees being treated with insecticide compared with perimeter row-treated plots, and a reduction of ≈93% compared with a standard full block sprays based on an average 1- and 2.5-ha block size in 2005 and 2006, respectively. Furthermore, in both 2005 and 2006, most growers actually stopped applying either trap tree or perimeter row sprays before reaching 171 DD_{10} threshold, the threshold identified by Reissig et al. (1998) in which insecticide applications are no longer needed. However, the degree-day estimates generated were based on temperature data gathered in nearby cities rather than directly within orchard sites, and therefore are likely less accurate estimates of the true accumulated degree-days.

One potential drawback of the trap tree approach is potential aggregation and subsequent injury in unbaited trees neighboring baited trap trees. In a previous study, Prokopy et al. (2004) demonstrated that a trap tree aggregated plum curculios within a trap tree and the resulting injury to fruit in the trap tree was greater than unbaited trees located 6–8 m away. In our 2005 study, there was some indication that unbaited trees located next to trap trees could be subject to increased aggregation of oviposition injury compared with other trees. In 2006, we quantified this effect specifically by comparing injury in the trees to the immediate left and right and in the first interior row from the trap tree with injury in the trap tree itself. In this case, there was no significant difference between injury in the trap tree and injury in the nearest neighbor trees indicating that aggregation and subsequent injury indeed encompassed an area greater than just the trap tree. However, when we compared injury in this trap tree zone (the trap tree and those three nearest neighbor surrounding trees) with injury in peripherally located trees in the trap tree plot (the second and third trees to the right and to the left of the trap tree and in third and fourth interior rows) (Fig. 2), injury in trap tree zones was significantly greater than peripheral zones indicating that such spillover would not be substantial beyond a couple of trees adjacent to trap trees. This spillover effect in neighboring trees may be due, in part, to the amount and timing of insecticide being applied in experimental blocks. In studies by Prokopy et al. (2004), trap trees were being used as monitoring tools, and when the threshold was reached the entire perimeter row was treated with insecticide rather than just the trap tree itself (current study). A second likely explanation involves the olfactory stimulants being deployed. The synergistic combination of benzaldehyde and grandisoic acid (Piñero and Prokopy 2003) strongly attracts adult plum curculios to traps before petal fall (Piñero et al. 2001, Piñero and Prokopy 2003, Leskey and Wright 2004b, Piñero and Prokopy 2006), but it becomes less attractive after petal fall owing primarily to olfactory competition with developing fruit (Leskey and Wright 2004a). If more competitive stimuli were identified and deployed in trap trees, perhaps based on preferred host fruit trees such as Japanese plum cultivars (Leskey and Wright 2007), the stimulus itself would be enhanced in such a way that more adults could be effectively aggregated within the single baited canopy itself rather than over a larger area. Alternatively, trap trees might require more frequent insecticide applications to maintain a lethal dose of insecticide, particularly if less persistent, reduced-risk materials are being applied. However, this aspect has not been investigated yet.

In conclusion, trap trees can be used as a management strategy against plum curculio in New England orchards provided that plum curculio pressure in a given orchard block is moderate or low. By correctly timing insecticide applications, satisfactory levels of control could be accomplished using this novel approach to managing plum curculio with a concurrent significant reduction in amount of insecticide applied. This management tactic could be improved by 1) replacing the end row insecticide treatment with several trap trees resulting in further insecticide reductions; 2) treating trap trees with insecticide at more frequent intervals to maintain an active residue; and 3) developing and deploying even more powerful attractants within tree canopies to increase aggregation and potentially reduce the number of trap trees required to successfully manage plum curculio.

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